We appreciate the comments from the reviewer and have taken the suggestions into account. In the following we respond to the remarks point by point. Our responses are in italics. Line numbers refer to the revision with changes marked. Changes in the manuscript have been marked in the following way: deleted text in red, new text in blue.

Anonymous Referee #1
(Received and published: 16 July 2018)
GENERAL COMMENTS
The present paper analyses a long-term time series of ground-based lidar data to derive properties of solar and lunar tides in noctilucent clouds. The properties of these weak features are difficult to extract out of all other components of atmospheric variability. Hence, long-term datasets are needed to be able to apply statistical methods. The present paper introduces a new and comparatively long dataset to this kind of research. This ground-based dataset has properties, which are complementary to those of the satellite datasets used before. It provides data for only one location but with a much better temporal resolution, which allows for a direct identification of tides on timescales of hours to one day. Different properties of solar and lunar tides are successfully derived and, when possible, compared to previous results from other measurement techniques, showing agreement in many aspects. There are not many independent derivations of these properties in the literature and the comparison with this complementary dataset is very valuable. The paper is well-written and easy to understand. It fits well to the scope of ACP so that I recommend the publication after addressing some minor points listed below.

SPECIFIC COMMENTS
Page 2, line 22: "however, it takes one month to cover all lunar times": It could be helpful for the reader to explain this by 2 or 3 more sentences.

We have added text to clarify this relationship: page 2, lines 21-27.

Page 3, line 2: "the mean probability to observe NLC at this location is âĹij48 %": Is this information really useful? The reference of 6400 measurement hours appears to be quite arbitrary, as it depends on weather conditions, etc. One could use the total number of possible measurement hours within the 21 seasons, but still I am not sure if this information is needed. Please explain or change accordingly.

We find it indeed useful to bring up these numbers. First of all they indicate the mean state (here: NLC occurrence frequency) before variability is discussed later in the manuscript. They additionally show that the tracer for our investigation of tides should allow statistically robust conclusions because NLC are no seldom events at this location. Last but not least this large number of measurement hours is quite unique for a ground-based lidar at this geographic location (full sunlight during summer etc.). For these reasons we leave the numbers but adjusted the text for improved readability: page 3, lines 4-5.

Page 3, lines 5-8: "For details the reader is referred to Fiedler et al. (2009)": I would find it useful to add some more sentences on the calculation method, although Fiedler

et al. (2009) is referenced. This would make the article more self-contained and help to directly understand it for readers without a strong background in lidar remote sensing.

We have added text according to the suggestion: page 3, lines 8-17.

Page 3, line 15: "to the hourly mean values": It might not directly be clear that the mean values from the epoch averaging are meant in contrast to, e.g., an hourly averaged time series (other approaches fit the sinusoidal functions directly to time series). Using other words like "epoch averages" could make this clearer.

Done: page 3, line 25.

Page 3, line 17: "The mean NLC parameters are randomly diversified within their error bars (1000 times for each hour)": Which distribution function is used for this (e.g., are the random samples normally distributed with the standard deviation set to the error bars or are they uniformly distributed with sharp edges at the error bar range)?

The random samples are uniformly distributed within the error bar range, which results in a larger error bar compared to the Gaussian weighted random distribution.

Page 3, line 23 and Figure 1, caption: "The plots contain 6400 hours of lidar mea-surements": Is this really the average over all available measurement hours or the average over the 3100 hours, which contain NLC? If 6400 hours is correct: Is it useful to integrate the measurements without NLC in this plot? To my understanding, these measurements are not used in the rest of the analysis and I would have expected to apply the same filters as for the analysis here.

The phrasing is something inexplicit, the 6400 hours apply for the occurrence frequency, for brightness only times with NLC detections are valid (3100 hours).
We corrected the text accordingly: page 3, line 33 – page4, line 1 ; Figure 1 caption.

Page 4, line 22: "The plots contain 3450 measurement and 2030 NLC hours from 1997 to 2017": a similar question here: Are the measurement hours without NLC averaged into to mean data? Or what does the differencing between measurement and NLC hours actually mean?

We think that rephrasing the text (see above) allows the reader to understand the numbers now.

Page 5, line 1: "most intense for occurrence frequency": According to the Delta-value in the plots, the total backscatter coefficient varies most. So, to which value is this statement related?

You are right, we meant the match between measurement and fit. Text is removed: page 5, lines 11-13.

Page 5, line 19ff: You compare your values of the semidiurnal amplitudes A12 to those of the satellite studies. As you mention also in the introduction, it takes about one month for sun-synchronous satellites to sample all local lunar times. Hence, the satellites strictly observe a superposition of a semidiurnal and a semimonthly lunar tide and it is necessary for the interpretation to assume that the semidiurnal tide dominates over the semimonthly tide. This assumption is commonly made, but is sometimes still under debate. Could you comment on, first, to what extent the good matching of your results with the satellite results support this assumption and, second, if it could be possible in future to also extract the semimonthly tide from your data in order to cleanly separate both?

From the match of both results one could deduce a dominating semidiurnal component. Basically our data allow such investigations, which will be subject of future work. Nevertheless we added text to make the reader aware of this topic: page 6, lines 4-6.

Page 6, Line 13: "the observed lunar tidal behavior, different for the NLC parameters": the phrasing is not very clear to me. Maybe the sentence could be restructured to put emphasis on the "different" and not on "all. . .contribute".

Done: page 6, lines 29-30.

Page 8, Line 33: "The altitude structure of the lunar semidiurnal tide in layered phenom-ena of the summer mesopause region was never studied so far": To my understanding, this is not true in this generality. E.g., von Savigny et al., 2017 shows the altitude structure of the semidiurnal lunar tide in MLS temperature up to 90km altitude and also Hoffmann et al., 2018 shows the altitude dependence of the semidiurnal lunar tide in several NLC related parameters. However, I agree that the phase progression has not been quantified and discussed in these studies as the authors do it here.

We changed the text to be more specific: page 9, lines 13-14; page 10, line 4.

TECHNICAL CORRECTIONS
Page 1, line 25: "even when epoch averaging over many years and where attributed to impacts of atmospheric thermal tides": A bit hard to understand. First, maybe: "when epoch averaging over many years is applied" and second, "where" has probably to be "were".

Done.

Page 4, line 22: "The plots contain 3450 measurement", add "s" to measurement

Both numbers are in units of hours: "3450 measurement and 2030 NLC hours". We changed the text for a better understanding: page 4, lines 32-33.

We appreciate the comments from the reviewer and have taken the suggestions into account. In the following we respond to the remarks point by point. Our responses are in italics. Line numbers refer to the revision with changes marked. Changes in the manuscript have been marked in the following way: deleted text in red, new text in blue.

Anonymous Referee #2
(Received and published: 13 July 2018)
SUMMARY
This paper extends other recent studies of lunar tide effects in noctilucent cloud (NLC) observations by using the long data record (21 years) of lidar measurements collected at the ALOMAR observatory in Norway. The lidar measurements supplement other satellite data sets because all local times are sampled, which improves the ability to separate solar and lunar tidal signatures. These data have been used successfully in many other studies of NLC behavior.

This paper is well-written, and the results are generally reasonable. Some suggestions and comments related to specific items are provided below.

SPECIFIC COMMENTS
1. p. 3, line 11: Please give 1-2 references for examples of the application of the superposed epoch analysis method.

We have referenced the first application of this method by Chree, 1912: page 3, line 20.

2. p. 3, line 15: Extending the harmonic fit analysis to a 4th order term (period = 6 hours) requires high data quality to ensure that small noise fluctuations do not alias into apparent real behavior. Given the small magnitudes that are reported for this term in Table 1, is there any to demonstrate statistically that using it is valid?

6 hour periods are frequently found in lidar observation, e.g. Fricke-Begemann and Höffner [2005], which is the main reason for including the 4th order term in our work. We find the data quality of the solar time series sufficient for this (correlation coefficients between fit and data are close to 1, see Table 1), and use this term for the lunar time series for homogeneity. As you see we have not scientifically interpreted the 6-hour results. On the other hand it appears useful to show the result for 2 reasons. At first it demonstrates that these short periods are (mostly) of small magnitude and do barely contribute to the overall tidal variations. At second it is important to include them for the simulations of the mutual residual impact between solar and lunar tidal oscillations (reliability of tidal parameters). See also point 6 below.

3. p. 4, lines 16-21: The magnitude of the data reduction with the use of a "core" season is not that much different than the reduction when a long-term brightness limit is imposed (35% vs. 48%). It seems more likely that the brightness threshold eliminates some faint clouds that have a greater relative response to the weak lunar signal, whereas the use of a core season may actually improve the opportunity to identify this signal because faint clouds have better background conditions in which to form. If the

authors agree with this premise, I suggest adding it to the discussion.

The long-term brightness limit (BETAmax > 4) removes all faint clouds (1 < BETAmax < 4) which results into completely separated data sets. We also investigated these 2 data sets and found lunar tidal signatures in both of them. Also, the seasonal dependence of faint clouds occurrence is smaller compared to that of brighter clouds, cf. Schmidt et al. [2018] (Fig. 3), which is caused by the seasonal variation of temperature and water vapor. This suggests that faint clouds are not primarily responsible for lunar tidal signatures in the overall NLC population.
We did a small text adjustment: page 4, lines 27-28.

4. p. 5, lines 7-8: Fiedler et al. [2011] show significant interannual variation in amplitude and phase of solar tidal components in NLC properties measured at ALOMAR over 14 years. If similar variations are present in lunar tidal behavior, does that cause a problem for the application of the superposed epoch analysis method, which combines data taken during many separate years?

Such variations would certainly impact the results extracted from this method. We have tried to investigate this topic by splitting the data set (first and last half of the time series). However, despite our large database covering 21 years it seems to be still too small for such investigations.

5. p. 5, lines 21-22: Note that von Savigny et al. [2017] and Hoffman et al. [2018] only present a semi-diurnal variation (as a single fit). So you should be careful in evaluating the agreement (or difference) between amplitudes and phases derived from those analyses vs. the 4-term results presented here. I would not expect complete agreement even if the same data set was examined because of the extra terms present in the 4-term fit.

In principle we agree, but comparing fits and original data at Fig. 2 in von Savigny et al. [2017] suggest barely other periods than a semi-diurnal variation. So, comparing their 12-hour components with ours should be appropriate. See also next point.

6. p. 6, lines 12-14: Some of the terms in the lunar tidal results are barely larger than their 1-sigma uncertainty (e.g. 6-hour period for OF, 12-hour and 8-hour period for Bmax). Since the original lunar signal is fairly weak, are you sure that all of these terms are really significant? Have you looked at fit results using only 2 or 3 terms?

Yes, indeed we calculated all fit results not only for the 4-term version but also for only 2 terms (24- and 12-hour periods) in order to check the influence of the additional terms. It turned out that the fit algorithm is fairly robust, the amplitudes and phases resulting from both fit versions are close to each other. For example, for the 12-hour component of Bmax the deviations between including/omitting 8-hour and 6-hour periods are: 1.7% for amplitude value, 1.0% for amplitude error, 8.7% for phase value, 3.9% for phase error.
We added this information to the text: page 5, lines 18-22.

7. p. 7, lines 28-30: What is the meaning of a negative vertical wavelength? Is this related to the sign of the phase term?

Yes, the phase is decreasing with increasing altitude.

8. p. 8, lines 30-32: Would you expect that a nadir-viewing instrument (such as SBUV), that integrates the NLC signal vertically, would see something like a linear sum of the frequency values at each altitude? Or would it see a weighted sum because the larger (brighter) ice particles are present at lower altitudes?

Good question ..., we would expect that such instrument would see a weighted sum because the vertical integration of the scattered light should be dominated by the brighter ice particles. Compared to the lidar, the SBUV signal has a weaker dependence on particle size (r^3 versus r^6) which should result in a weaker weighting. Additionally the anti-correlation between number density and size of the particles might further weakening the weighting.

TYPOGRAPHICAL ERRORS AND GRAMMATICAL SUGGESTIONS
p. 1, line 21: "waver" should be "water".
p. 2, line 2: "Prominent influence have diurnal and semidiurnal components" could be changed to "Diurnal and semidiurnal components have a prominent influence".
p. 2, line 6: "in atmosphere" should be "in the atmosphere".
p. 2, line 18: "overhead" could be changed to "above".
p. 2, line 31: "begin of" should be "the beginning of".

All done.

p. 3, line 1: "a subset of 3100 hours" could be changed to "with a subset of 3100 hours that".

Already changed due to comments by the other reviewer.

p. 4, line 19: "restricts to" could be changed to "restricts the sampling to".
p. 4, line 28: "observed 1997" should be "observed in 1997".
p. 5, line 27: "Limp" should be "Limb".
p. 6, line 8: "make aware" could be changed to "make the reader aware".
p. 6, line 28: "results into" could be changed to "results in".

All done.

p. 6, line 34: "only be small impacted" could be changed to "have only a small impact".

We leave it like it is.

p. 9, line 21: "vertical" should be "vertically".

Already changed due to comments by the other reviewer.

p. 9, line 22: "hinting for" could be changed to "suggesting".

Done.

References:

Fricke-Begemann, C., and J. Höffner (2005), Temperature tides and waves near the mesopause from lidar observations at two latitudes, J. Geophys. Res., 110, D19103, doi:10.1029/2005JD005770.

Schmidt, F., Baumgarten, G., Berger, U., Fiedler, J., Lübken, F.-J. (2018), Local time dependence of polar mesospheric clouds: a model study, Atmos. Chem. Phys.,18, 8893–8908, doi:10.5194/acp-18-8893-2018.

Solar and lunar tides in noctilucent clouds as determined by ground-based lidar

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Abstract.

Noctilucent clouds (NLC) occur during summer from mid to high latitudes. They consist of nanometer sized ice particles in an altitude range from 80 to 90 km and are sensitive to ambient temperature and water vapor content, which makes them a suitable tracer for variability on all time scales. The data set acquired by the ALOMAR RMR-lidar covers 21 years and is investigated regarding tidal signatures in NLC. For the first time solar and lunar tidal parameters in NLC were determined simultaneously from the same data. Several NLC parameters are subject to persistent mean variations throughout solar as well as lunar day. Variations with lunar time are generally smaller compared to variations with solar time. NLC occurrence frequency shows the most robust imprint of the lunar semidiurnal tide. Its amplitude is about 50 % of the solar semidiurnal tide, which is surprisingly large. Phase progressions of NLC occurrence frequency indicate upward propagating solar tides. Below 84 km altitude the corresponding vertical wavelengths are between 20 and 30 km. For the lunar semidiurnal tide phase progressions vary symmetrically with respect to the maximum of the NLC layer.

1 Introduction

Noctilucent clouds (NLC) are a phenomenon of the mesopause region from mid to high latitudes. During summer temperatures fall below 150 K and cause the few ppmv of water vapor at these altitudes to freeze. The result are tiny ice particles which are observable by naked eye. First documented observations have been made during summer 1885 (Backhouse, 1885; Jesse, 1885; Leslie, 1885) and the altitude of the clouds was determined to about 83 km by optical triangulation (Jesse, 1896).

It has been shown that NLC consist of few tens of nanometer sized, aspherical ice particles with a number density of about hundred per cm³ (e.g., von Cossart et al., 1999; Hervig et al., 2001; Baumgarten et al., 2002). NLC displays often show pronounced variability, which provides information about dynamic processes like horizontal wind and wave motions in their environment (Witt, 1962). Mesospheric ice particles are extremely sensitive to changes of atmospheric background parameters, like temperature and ~~waver~~ water vapor, and have been demonstrated to respond to various scales of variability, ranging from seconds to years (e.g., Thomas et al., 1991; Kirkwood and Stebel, 2003; Merkel et al., 2003; DeLand et al., 2003; Kaifler et al., 2013; Russell III et al., 2014; Fiedler et al., 2017).

One particular scale of interest are variations with solar time (e.g., von Zahn et al., 1998; Chu et al., 2001; Fiedler et al., 2005; Gerding et al., 2013). Such oscillations have been found to be persistent even when epoch averaging over many years is

applied and where attributed to impacts of atmospheric thermal tides (e.g., Fiedler et al., 2011; Stevens et al., 2017). Solar tidal oscillations are globally forced due to absorption of solar irradiance throughout the day. ~~Prominent influence have d~~Diurnal and semidiurnal components have a prominent influence, ~~which~~ they are stimulated by absorption of solar radiation in the near-infrared bands of tropospheric water vapor and solar ultraviolet radiation by stratospheric ozone and mesospheric molecular oxygen, respectively (e.g., Chapman and Lindzen, 1970; Forbes, 1984).

The moon forces gravitational tidal signatures not only in Earth's oceans but also in the atmosphere. Sabine (1847) published the first reliable identification of lunar tidal signatures in surface pressure data. The semidiurnal lunar tide is the most significant component and was found in several parameters even in the mesosphere and lower thermosphere like winds, temperatures and airglow emissions (e.g., Stening et al., 1987; Paulino et al., 2013; von Savigny et al., 2015). Studies of lunar tidal signatures in NLC are sparse and mostly based on ground-based visual observations (e.g., Kropotkina and Shefov, 1975; Gadsden, 1985; Dalin et al., 2006). Only recently the lunar semidiurnal tide was identified in multi-year data sets of satellite instruments (von Savigny et al., 2017; Hoffmann et al., 2018). Ground- and satellite-based results partly differ from each other, especially for the lunar tidal amplitude.

In general, available observation methods of tides in NLC have different pros and cons. Ground-based visual data can only be obtained around solar midnight hours where the lower troposphere is dark but sunlight still illuminates the upper mesosphere and is scattered at the ice particles. This hampers the identification of both solar and lunar tidal signatures. Ground-based lidars can cover the entire solar diurnal cycle and are thus able to identify solar and lunar tides. As they operate at fixed locations, the superposition of all tidal components ~~overhead~~ above the instrument is measured, with the migrating components giving the distinct variations with solar time. Solar and lunar semidiurnal periods are close to each other (12.0 vs. 12.4 solar hours) and a separation requires adequate sampling and data accuracy. Satellite instruments usually operate in sun-synchronous orbits and cover only few solar times during longer time periods. ~~, which hampers the identification of solar tidal signatures. They sample continuously and have less deterioration of the lunar signal by solar impacts, however, it takes one month to cover all lunar times.~~ On the one hand this hampers the identification of solar tidal signatures, on the other hand they have less deterioration of the lunar signal by solar impacts. Moon's orbit around the Earth as well as Earth's rotation around its axis are of identical direction, however, Moon's orbital speed is slower. For this reason its apparent earth revolution takes about 50 minutes longer than 24 hours, which accumulates to a full day within a month's period. Hence it takes one month for sun-synchronous satellites to cover all lunar times.

In this study we will extract for the first time solar and lunar tidal signatures in NLC simultaneously from a multi-year data set obtained by ground-based lidar. Moreover, phase progressions will be addressed by investigation of altitude resolved tidal parameters.

2 Data analysis

We use data obtained by the Rayleigh/Mie/Raman-(RMR-) lidar at the ALOMAR research station in Northern Norway (69° N, 16° E). The lidar is in regular operation since 1997 and is intensely used during the summer months for NLC detections

whenever weather conditions permit. Because of the technical setup NLC are detectable during all local times, even during the highest solar elevation angles around $44°$. NLC above ALOMAR usually occur between beginning of June and mid August, leading to our definition of the season length from day of year (DoY) 152 (1 June) to 227 (15 August). The data set covers 6400 measurement hours during 21 seasons~~, a.~~ A subset of 3100 hours contains NLC~~. Hence, the mean probability to observe~~
~~NLC at this location is ~48 %.~~ , yielding a mean probability of $\sim48\,\%$ to observe NLC at this location.

The lidar transmitter emits light at 532 nm wavelength with approx. 50 MW power per laser pulse. Part of it is backscattered by air molecules and NLC particles and detected by the receiver, together with sunlight scattered by the atmosphere. ~~After background subtraction the volume backscatter coefficient as function of altitude $\beta_{\mathrm{NLC}}(z)$ is calculated. Values larger~~ ~~than zero indicate the presence of aerosol particles and are a measure of the cloud brightness. The following NLC parameters~~ ~~are extracted: occurrence frequency (OF), centroid altitude, maximum backscatter coefficient of the altitude profile ($\beta_{\overline{\max}}$),~~ ~~and total backscatter coefficient of the column (β_{tot}).~~ After background subtraction the received signal is first converted into a backscatter ratio $R(z)$, which is a measure for the presence of aerosol particles and defined as the ratio of the measured total signal to the molecular signal $\beta_{\mathrm{M}}(z)$. Then the volume backscatter coefficient of NLC particles $\beta_{\mathrm{NLC}}(z) = (R(z)-1) \times \beta_{\mathrm{M}}(z)$ is calculated, $\beta_{\mathrm{M}}(z)$ is calculated from air densities for the lidar location (Lübken, 1999). From the altitude profile $\beta_{NLC}(z)$ we determine the maximum value β_{max}, the total backscatter coefficient β_{tot} (integral over the vertical layer extension) and the centroid altitude. The ratio of time with NLC signatures over total measurement time yields the occurrence frequency (OF). For more details the reader is referred to Fiedler et al. (2009). To maintain homogeneous conditions during 21 seasons, the data were pre-integrated in time and altitude for about 15 min and 150 m.

In a next step, the measurements were sorted by local time, i.e. the individual pre-integrations were accumulated and averaged in their corresponding hourly time slots. This method is usually called superposed epoch analysis (Chree, 1912) and was applied for solar as well as lunar times separately. Lunar, like solar, time follows from the azimuth position of the celestial body relative to the observer. For a given solar time Moon ephemerides were calculated using the 'PyEphem' library (https://pypi.python.org/pypi/pyephem). To extract tidal information from the temporal variations of NLC parameters, least-square fits of the sum of sinusoidal functions with periods of 24, 12, 8, 6 hours to the hourly mean values (solar as well as lunar epoch averages) were performed. Confidence intervals of the estimated fit parameters were calculated with the bootstrap method by resampling the data set within the uncertainties of the means (e.g., Efron and Tibshirani, 1993). The mean NLC parameters are randomly diversified within their error bars (1000 times for each hour), which results in an equivalent number of time series for which the fits are determined. Finally, the statistics of the distribution of each fit parameter is calculated, resulting in a mean value and its error.

3 Results and discussion

3.1 Variations with solar time

Fig. 1 shows the mean variations of NLC occurrence frequency and brightness with altitude and time. The plots contain 6400 measurement hours including 3100 hours with NLC and were composed using ~~each single altitude profile of the NLC brightness~~

Fig.1

3

individual altitude profiles from 1997 to 2017. NLC above ALOMAR can virtually exist in the entire altitude range between 78 and 90 km. They occur most often and have the largest vertical extent between midnight and 6 local solar time (LST), which was attributed to thermal tides at 83 km altitude (Fiedler et al., 2011). The altitude of maximum occurrence decreases by about 1 km during the morning hours. A second and weaker occurrence maximum is visible around 15 LST. The clouds reach

5   their maximum brightness between 3 and 9 LST, which is 3 hours later compared to the occurrence maximum. Nevertheless relatively strong (brighter) clouds contribute to this occurrence maximum. The secondary occurrence maximum, however, is caused only by fainter (dimmer) clouds. The altitude structure of brightness mirrors the growth-sedimentation scenario of NLC particles. They nucleate at low temperatures in the mesopause region around 88 km, grow in size by the uptake of water vapor and decrease in altitude due to selective turbulent diffusion and gravitation. The observed brightness depends strongly

10   on particle size ($\propto r^6$). Temperature increases with decreasing altitude, which causes the ice particles to sublimate. This leads to a sharp brightness decrease at the lower border of the particle existence range.

We like to point out that from measurements at one location one cannot prove that observed local time dependent features are caused by tides. However, the persistence of features in our 21 year data set shown in Figure 1 is a strong hint for atmospheric tides. Imprints of variability sources uncorrelated to solar time, like gravity waves, should cancel out on these multi-year time

15   scales. Furthermore we observe a superposition of all existing tidal modes at a given time and cannot differentiate between migrating and nonmigrating parts.

3.2   Simultaneous solar and lunar tidal variations

We investigate the mean local time dependence of NLC parameters using a representative brightness value for each altitude profile. This method was applied earlier for our data set and is commonly used for ground-based lidars as well as satellite in-

20   struments. We determine for each altitude profile the value of the maximum brightness β_{max} as well as the integrated brightness β_{tot} over all altitudes. Local time variability of NLC parameters depends on cloud brightness and its observation is additionally impacted by instrument sensitivity (e.g., Fiedler et al., 2005, 2011). For these reasons we usually apply a minimum brightness limit. In this study, however, we aim on the identification of weak lunar signals embedded in a larger background of solar variability. The frequency distribution of brightness values satisfies an exponential law (cf. Fig. 1 in Fiedler et al. (2017)) with

25   a high occurrence of dim clouds. As a result, the application of our long-term brightness limit ($\beta_{\mathrm{max}} > 4 \times 10^{-10}\,\mathrm{m}^{-1}\,\mathrm{sr}^{-1}$) reduces the NLC detections by 48 % from 3100 to 1600 hours. Sensitivity tests showed that data reductions of such extent prevent a reliable extraction of the lunar signal from our data set. It turned out that an exclusive limitation to the core of the season (without application of any brightness limit) is better suited as it restricts the sampling to stable summer conditions with high NLC occurrences. Therefore we choose a time period where the daily NLC occurrence frequency exceeds the seasonal

30   mean value, which is roughly the case between DoY 170 (19 June) and 210 (29 July); cf. Fig. 3 in Fiedler et al. (2009) and Fig. 2 in Fiedler et al. (2017). This reduces the NLC detections by 35 %.

The resulting solar and lunar time variations are shown in Fig. 2 . The plots contain 3450 measurement hours including and **Fig.2** 2030 hours with NLC hours from 1997 to 2017. Throughout the solar day the results match the variations seen in Figure 1. We again find the highest NLC occurrence between midnight and 6 LST and a weaker maximum around 15 LST. The maximum

brightness is observed between 3 and 8 LST. Highest altitudes are reached around midnight and 14 LST, the mean altitude variation during solar day is ∼1.1 km. The daily variations of brightness and altitude are anti-correlated (r = −0.84), i.e. brightest clouds occur at lowest altitudes and vice versa, which fits the above-mentioned growth-sedimentation scenario of mesospheric ice particles.

5   Such distinct variations throughout the solar day were first observed in 1997 at ALOMAR and have been found by ground-based lidar at other locations as well (e.g., von Zahn et al., 1998; Chu et al., 2001; Fiedler et al., 2005; Gerding et al., 2013). Satellites mostly operate in sun-synchronous orbits and are thus not able to cover NLC local time variations, with some exceptions (e.g., Stevens et al., 2009; DeLand et al., 2011). NLC variability during solar day was also investigated by models (e.g., Stevens et al., 2010, 2017; Schmidt et al., 2018). In general, maximum values for occurrence and brightness are found in

10   the first half of the solar day, which is attributed to temperature tides and tidal variations in background water vapor.

     Figure 2 shows also the NLC parameters as function of local lunar time (LLT)~~. We~~ and we find variations in all parameters. ~~, most intense for occurrence frequency. The signatures in altitude and brightness are less pronounced and better visible during the first half of the lunar day.~~ NLC occur most often around 3 and 11 LLT. The highest altitude is reached around 2 LLT, which is connected with a minimum in brightness. Variations with LLT are smaller compared to that with LST. The relative variation

15     $\Delta = (\max - \min)/\text{mean}$ during solar (lunar) day is 60.9 % (21.5 %) for occurrence frequency, 1.4 % (0.4 %) for altitude, 74.4 % (15.8 %) for maximum brightness, and 92.8 % (25.7 %) for total brightness.

     To compare the impact of solar and lunar tides on NLC we extracted amplitudes (A) and phases (P) of fits up to the 4th harmonic of the day to the data. The results are listed in Table 1 . For checking purposes we calculated the fits addionally for only 2 harmonics (24-hour and 12-hour periods). It turned out that the fit algorithm is fairly robust, the amplitudes and phases

20   resulting from both fit versions are close to each other. For example, for the 12-hour component of the maximum brightness the deviations between including/omitting 8-hour and 6-hour periods are: 1.7 % for amplitude value, 1.0 % for amplitude error, 8.7 % for phase value and 3.9 % for phase error. We note the only moderate correlation coefficients for altitude and especially brightness variations with lunar day, indicating these parameters to be additionally impacted by other sources of variability. Solar tidal variations are dominated by diurnal and semidiurnal periods. Amplitude ratios A_{24}/A_{12} are 1.8, 2.1 and 2.5 for

25   occurrence frequency and brightness (maximum, total), respectively. For altitude both periods identically contribute to solar time variations.

     Investigations of NLC regarding lunar tidal signatures are sparse and mostly based on ground-based visual observations. Such observations are limited to a couple of hours around midnight because of the illumination conditions of mesospheric altitudes by the sun. The results partly differ from each other and show lunar variations of the NLC occurrence with amplitudes

30   from 4 to 30 % in a months period (e.g., Kropotkina and Shefov, 1975; Gadsden, 1985; Dalin et al., 2006). Only recently lunar tides in NLC were identified in multi-decade data sets of SBUV (Solar Backscattered Ultraviolet) satellite instruments (von Savigny et al., 2017). The authors found clear lunar semidiurnal tidal signatures in NLC occurrence frequency, albedo, and ice water content. For the northern hemisphere (55°–75° N) they extracted a relative amplitude A_{12}(rel) of 5.2 % and a phase P_{12} of 3.3 h LLT for the NLC occurrence frequency, which is so far the only value determined by instrumental obser-

35   vations. The present study is the first identification of lunar tidal signatures in ground-based lidar observations. Our values of

<div align="right">**Tab.1**</div>

$A_{12}(rel) = 6.8\,\%$ and $P_{12} = 2.0\,h$ LLT are in good agreement with von Savigny et al. (2017). From visual NLC observations published by Gadsden (1985) follow maximum NLC occurrences around 3 h LLT (cf. discussion in von Savigny et al. (2017)). Thus three independent data sets show occurrence maxima between 2 and 3 h LLT, which hints to a robust determination of the corresponding semidiurnal lunar tide. One should keep in mind that sun-synchronous satellite instruments cannot distinguish between the semidiurnal and the semimonthly lunar tide and thus measure a superposition of both components. It is commonly expected that the semidiurnal component dominates, which is, however, still debated (cf. discussion in Hoffmann et al. (2018)).

von Savigny et al. (2017) suggested temperature variations in the mesopause region as main driver of lunar tidal signatures in NLC. They investigated 7 years of satellite temperature data from the MLS (Microwave Limb Sounder) instrument and found at 83 km altitude consistent features with respect to lunar NLC variations, namely minimum temperatures from 1 to 4 h LLT. Hoffmann et al. (2018) analyzed 9 years of data from the SOFIE (Solar Occultation for Ice Experiment) satellite instrument and found temperature variations with LLT as well. In general temperature variations with lunar time are very small with maximum amplitudes of about 0.2 K.

Brightness related parameters (albedo, ice water content) were determined by von Savigny et al. (2017) to be $A_{12}(rel) \sim 6\,\%$ and $P_{12} \sim 3\,h$ LLT. Hoffmann et al. (2018) found in SOFIE data $A_{12}(rel) = 2.5\,\%$ and $P_{12} = 2.5\,h$ LLT for the ice water content in the northern hemisphere. Our values of $A_{12}(rel) = 2.1\,\%$ and $P_{12} = 4.4\,h$ LLT for brightness (β_{tot}) match reasonably the satellite data. We notice, however, that the semidiurnal component is the weakest of all extracted harmonic components for our NLC brightness (cf. Table 1). The superposition of all four oscillations results into a brightness minimum around 2 h LLT, compared to a maximum in the satellite observations. Hoffmann et al. (2018) also extracted lunar tidal NLC altitude variations, which were determined to $A_{12}(abs) = 60\,m$ and $P_{12} = 2.2\,h$ LLT. This fits remarkably our values of $A_{12}(abs) = 80\,m$ and $P_{12} = 0.9\,h$ LLT. A difference between satellite results and the present study is the phasing of altitude to brightness. Whereas Hoffmann et al. (2018) find them to be in phase (clouds with larger ice water content are at higher altitudes), our results show the common anti-phase behavior known from solar tidal variations (cf. Figure 2). When only the semidiurnal components are taken into account, the lunar phases of altitude and brightness (β_{tot}) differ by about 3.5 hours, which is midway between in phase and anti-phase. We make the reader aware that the statistical significance for our brightness fits is relatively low and thus this particular result should not be overestimated, see also below.

From Table 1 we find solar tidal amplitudes to be always larger than lunar ones, which is expected. For example, the ratios of semidiurnal solar to lunar amplitudes are ~ 1.9 for occurrence frequency, ~ 4.1 for altitude, and ~ 7.5 for brightness. Dalin et al. (2017) extracted this ratio to ~ 7.7 for horizontal winds from radar measurements in the mesopause region at $68°$ N. For our data set we notice that ~~all four~~ the extracted harmonics contribute differently to the observed lunar tidal behavior~~, different for~~ of the NLC parameters. For occurrence frequency and altitude the semidiurnal component is dominating, whereas it is the weakest one for brightness. From models a diurnal lunar tide is anticipated to be significantly smaller compared to the semidiurnal lunar tide (e.g., Chapman and Lindzen, 1970; Pedatella et al., 2012). Stening (1989) found a diurnal modulation of the lunar tide and suggested this to be caused by interactions with solar tides during upward propagation of the lunar tide, cf. also Stening and Vincent (1989). Concerning the 8-h and 6-h LLT oscillations we see no resilient reason to attribute it to be directly caused by the Moon and will estimate the robustness of extracted lunar oscillations in the following chapter.

3.3 Reliability of tidal parameters

For analysis of simultaneous solar and lunar tidal variations we use 41 days in the core of the NLC season (DoY 170–210). As our measurements cover many solar times and solar tidal amplitudes are large, the actual distribution of measurements times during each year might cause a residual impact on the extracted lunar amplitudes (sampling issue). This would introduce a systematic error on top of the statistical error of the lunar tidal parameters. We investigated this topic using the following simulations.

At first the mean solar time dependencies for NLC occurrence frequency, altitude and brightness were reconstructed using amplitudes and phases of the harmonic solar periods. Then the constructed NLC parameter value at the solar time of each actual measurement was taken and assigned to the corresponding lunar time (method 1). This results in~~to~~ mean lunar time dependencies for the NLC parameters which should be ideally flat curves representing the mean values of the NLC parameters. We find deviations from this ideal case indicating residual impacts from solar onto lunar tidal parameters (thick green curves in left panels of Fig. 3). For occurrence frequency enhanced values are visible from 4–6 LLT and from 11–16 LLT. For altitude **Fig.3** enhanced values show especially from 10–12 LLT and decreased values from 16–18 LLT. The measured hourly mean values with respect to lunar time are also shown for reference (blue symbols and curves in left panels of Fig. 3). Comparing these curves with the simulations we find NLC occurrence frequency as well as altitude only be small impacted during lunar morning, whereas during lunar afternoon solar impacts are large compared to the measured values. For NLC brightness the situation is worse. Here solar impacts reach larger values during extended lunar time periods, even during lunar morning.

We also calculated a second simulation (method 2). For this purpose, artificial solar times were randomly generated with the total number matching the number of measurements. Then, like in the first simulation, the constructed NLC parameter value at each artificial generated solar time was taken and assigned to the corresponding lunar time. This procedure was executed several times. The results are the thin green curves in the left panels of Fig. 3. Again we find residual solar tidal impacts, however, they do not exceed the ones from the first simulation.

In general, the actual sampling of the measurements concerning solar time impacts the extracted lunar time dependence of NLC parameters. This impact is smallest for occurrence frequency, moderate for altitude, and largest for brightness. We notice that 1.7 times more data are available for determination of occurrence frequencies (entire measurement time) compared to NLC layer parameters (only NLC measurement time). Thus, enhanced lunar amplitudes especially for the higher harmonics (8- and 6-h lunar periods) of altitude and brightness might be caused by an insufficient amount of data, although the data set covers 21 seasons.

For completeness we performed the same investigations regarding lunar residual impacts on solar tidal parameters. The results are shown in the right panels of Fig. 3 and indicate only negligible effects.

3.4 Altitude dependence of tidal parameters

Now we study altitude resolved tidal parameters. For this purpose the altitude range between 80 and 88 km was divided into 8 slices of 1 km extent each (cf. Fig. 1). For each altitude slice amplitudes (A_{24}, A_{12}) and phases (P_{24}, P_{12}) of diurnal and

semidiurnal harmonic oscillations were extracted. The result for solar tides is shown in Fig. 4 . Amplitudes of the occurrence
frequency reach values up to 10 %. The lower half of the altitude range is dominated by the diurnal component, being partly
1.9 times stronger compared to the semidiurnal component. At higher altitudes the amplitudes of both components decrease
and are nearly identical. The brightness shows roughly a similar behavior. The diurnal component dominates by a factor up to
5   2.2. However, the altitude dependences of A_{12} are different for occurrence frequency and brightness. While the former has its
maximum at 84.5 km, the one of the brightness is monotonically decreasing with increasing altitude.

Phases for both tidal components of occurrence frequency and brightness decrease continuously with altitude, as is expected for upward propagating tides, with only one exception (P_{12} of brightness). We notice the existence of two altitude
ranges with different phase progressions, separated at about 84 km. From the slopes we determined corresponding vertical
10   wavelengths λ_z which are also shown in Figure 4. For the occurrence frequency, vertical wavelengths in the lower altitude
range are -31 km (P_{24}) and -21 km (P_{12}). Values increase in the upper altitude range to -125 km (P_{24}) and -56 km (P_{12}).
For brightness we extract vertical wavelengths of -68 km (P_{24}) and -17 km (P_{12}) below 84 km altitude. Above this limit the
progression of P_{24} increases substantially, whereas progression of P_{12} tends to change sign. This phase behavior, however, is
accompanied by small amplitude values and might lack robustness. We notice that vertical wavelengths connected with diurnal
15   phases have generally larger absolute values compared to that of semidiurnal phases.

Hough modes of classical tidal theory are distinguished by their vertical wavelength (Chapman and Lindzen, 1970). Wavelengths between 17 and 21 km as they were observed for the semidiurnal tide below 84 km correspond to higher order Hough
modes H(2,9)–H(2,11). For the diurnal tide we find solely wavelengths ≥ 31 km which indicates negative Hough modes. We
note, however, that the excitation intensity of modes decreases towards higher latitudes according to linear theory. Thus at
20   69° N nonlinear wave interactions might play a major role.

To our knowledge, vertical phase progressions in NLC have never been published so far. Thus we compare our results to other
parameters like temperature and horizontal winds measured in the summer mesopause region. Lübken et al. (2011) investigated
thermal tides at Davis (69° S) by means of a resonance lidar. They found during January 2011 downward progressing P_{24} with
a vertical wavelength of -30 km between 84 and 89 km altitude. P_{12} shows the opposite behaviour, namely upward progression
25   (their Figure 3). Murphy et al. (2006) published a climatology of tides in the Antarctic mesosphere determined by radar wind
measurements. They found between December and February in the 80 to 86 km range vertical wavelengths from -37 km to
-55 km for P_{12} (migrating), but also values marked as *large*. Vertical wavelengths associated with P_{24} are large or even positive,
cf. their Figure 7. At mid-latitudes She et al. (2002) (Figures 2 and 3) found tidal temperature variations between 84 and 89 km
altitude during summer corresponding to vertical wavelengths of -27 km (P_{12}) and -19 km (P_{24}) using a resonance lidar.
30   Again at mid-latitudes, from lidar temperature soundings by Kopp et al. (2015) follow vertical wavelengths of -9 km (P_{12})
and -14 km (P_{24}) around 85 km altitude in July (cf. their Figure 7). These numbers might not be representative, as their results
show large variabilities during the summer period.

In general, solar tidal phases determined from our NLC observations show a consistent behavior indicating that corresponding vertical wavelengths are robust. The wavelengths fall within the range of values extracted from other measurements
35   published in the literature. We notice the variability of λ_z values which might be caused by different time periods covered by

the measurements (days to years) as well as the tidal variability itself. Changes in phase progressions around 84 km altitude could be caused by combined effects of tracer (ice particles) and background atmosphere. With increasing altitude the particle size decreases towards the mesopause at around 89 km where they nucleate. Simultaneously, turbulent mixing of the background atmosphere increases with altitude which impacts the microphysical properties of NLC particles. Baumgarten et al. (2010) found a correlation between particle size and distribution width for mean sizes up to 40 nm, which are reached at an altitude of about 84 km. For larger particles (lower altitudes) the distribution width is roughly constant. Following this, one could speculate that tidal impacts might depend on the turbulent regime of the atmosphere.

We have shown that occurrence frequency is the most robust NLC parameter of our data set concerning lunar time variations. Therefore we investigated the altitude dependence of its semidiurnal component by applying the same procedure like for solar time variations. The results are shown in Fig. 5 . The semidiurnal component maximizes shortly above the altitude of maximum **Fig.5** occurrence frequency. Phases vary between 1.5 and 4.4 h LLT, their progression is positive below 84 km and negative above. Corresponding vertical wavelengths are approx. −27 km and +36 km.

~~The altitude structure~~ Phase progressions of the lunar semidiurnal tide in layered phenomena of the summer mesopause region ~~was~~ were never studied so far. Paulino et al. (2013) found in temperature data of the SABER (Sounding of the Atmosphere Using Broadband Emission Radiometry) satellite instrument both positive and negative phase progressions between 80 and 90 km altitude, depending on latitude. They also identified several modes of the lunar semidiurnal tide, including nonmigrating, and suggested an interaction between lunar tide and other tides and/or waves at higher altitudes.

4 Conclusions

The 21 years data set of the ALOMAR RMR-lidar contains the largest NLC archive acquired by ground-based lidar and was investigated regarding solar and lunar tides in NLC. Distinct variations with solar as well as lunar time were found in several NLC parameters. This study represents the first identification of lunar tidal signatures in ground-based lidar observations. The results may be summarized as follows.

1. Throughout the solar day the highest NLC occurrence frequency was found between midnight and 6 LST, the brightness maximizes between 3 and 8 LST, and highest altitudes are reached around midnight and 14 LST. Throughout lunar day NLC occur most often around 3 and 11 LLT and the highest altitudes are reached around 2 LLT. Variations with lunar time are generally smaller compared to variations with solar time.

2. Solar time variations are dominated by diurnal and semidiurnal tidal components. For NLC occurrence frequency and brightness the diurnal component is roughly twice as large as the semidiurnal component. For NLC altitude both components identically contribute to the variability.

3. The relative amplitude of the lunar semidiurnal tide in NLC occurrence frequency is 6.8 % and the phase is 2.0 lunar hours. The lunar semidiurnal tide in NLC altitude has an amplitude of 60 m and a phase of 0.9 lunar hours. Both findings are in good agreement with results from satellite observations.

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4. For the first time solar and lunar tidal parameters in NLC were determined simultaneously from the same data set. For occurrence frequency the lunar semidiurnal amplitude is approx. 50 % of the solar semidiurnal amplitude, which is surprisingly large.

5. We showed for the first time vertical ~~resolved tidal parameters~~ phase progressions in NLC. For occurrence frequency phases of solar diurnal and semidiurnal components decrease with altitude, ~~hinting for~~ suggesting upward propagating tides. Corresponding vertical wavelengths are -31 km and -21 km below 84 km and larger above. Lunar semidiurnal phases stay in the range between 1.5 and 4.4 lunar hours and vary symmetrically with respect to the maximum of the NLC layer. Corresponding vertical wavelengths vary from approx. -27 km to $+36$ km.

6. Simulations of sampling effects showed that the distribution of lidar measurements in terms of solar time has impacts on the extracted lunar tidal parameters. In this way solar tidal variations cause residual variations in terms of lunar time. Such impacts are smallest for occurrence frequency, moderate for altitude, and largest for brightness. On the other hand lunar tidal variations have negligible impact on extracted solar tidal parameters. Following this, trend investigations of our NLC time series are not significantly affected by lunar tidal variations.

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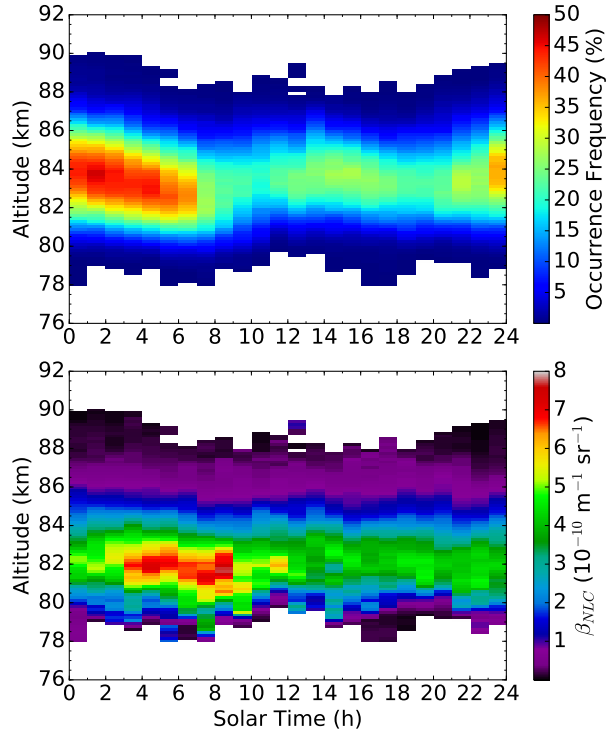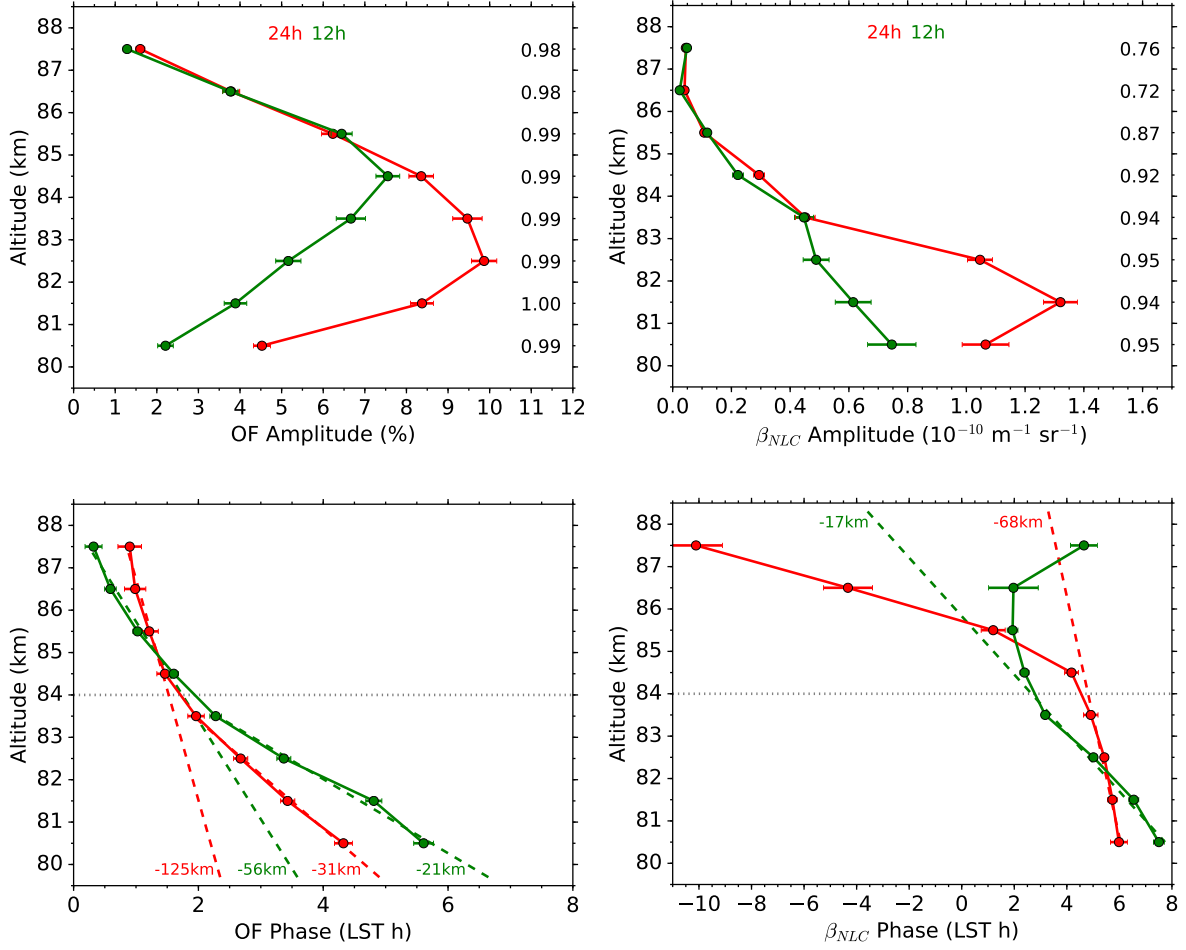
Figure 1. Mean altitude and solar time variations of NLC occurrence frequency (top) and brightness (bottom) between 1 June and 15 August from 1997 to 2017. ~~The plots contain 6400 hours of lidar measurements between 1 June and 15 August.~~ The plots are composed of altitude profiles covering 3100 hours of NLC detections, the upper panel contains 6400 hours total measurement time.
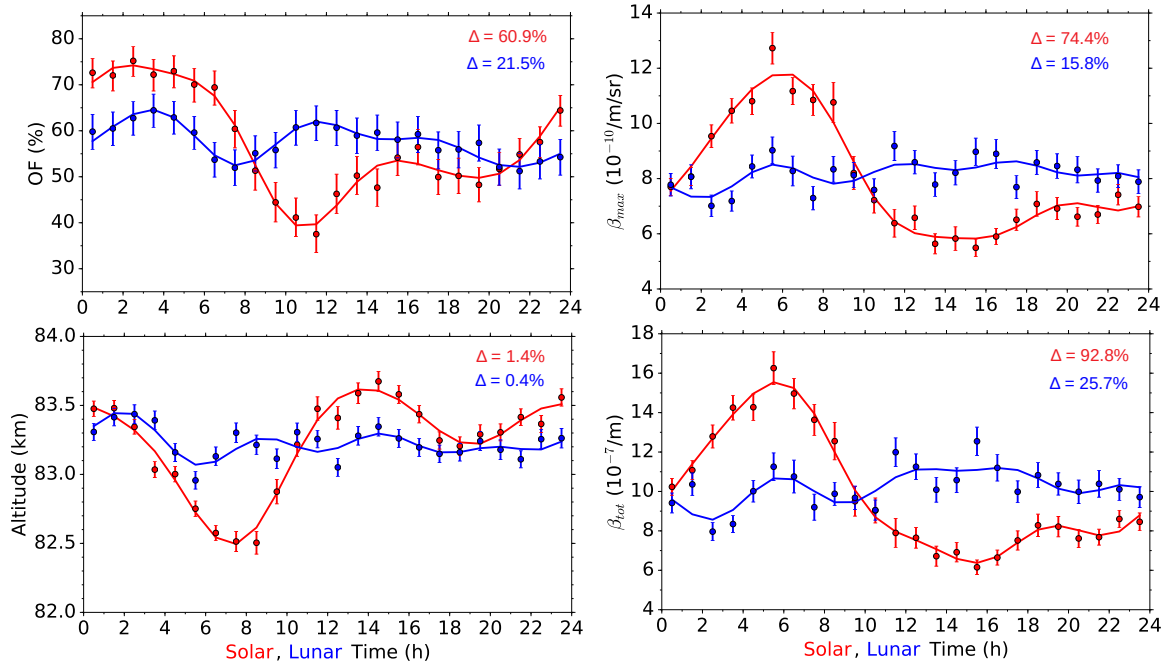
Figure 2. Mean solar (red) and lunar (blue) time variations of NLC occurrence frequency (OF), altitude and the maximum and integrated brightness (β_{max}, β_{tot}) between 19 June and 29 July from 1997 to 2017. Symbols are hourly mean values and vertical bars errors of the means. Solid lines are harmonic fits with periods of 24, 12, 8 and 6 hours to the mean values. The relative variations of the fits over day $\Delta = (\mathrm{max} - \mathrm{min})/\mathrm{mean}$ are indicated.
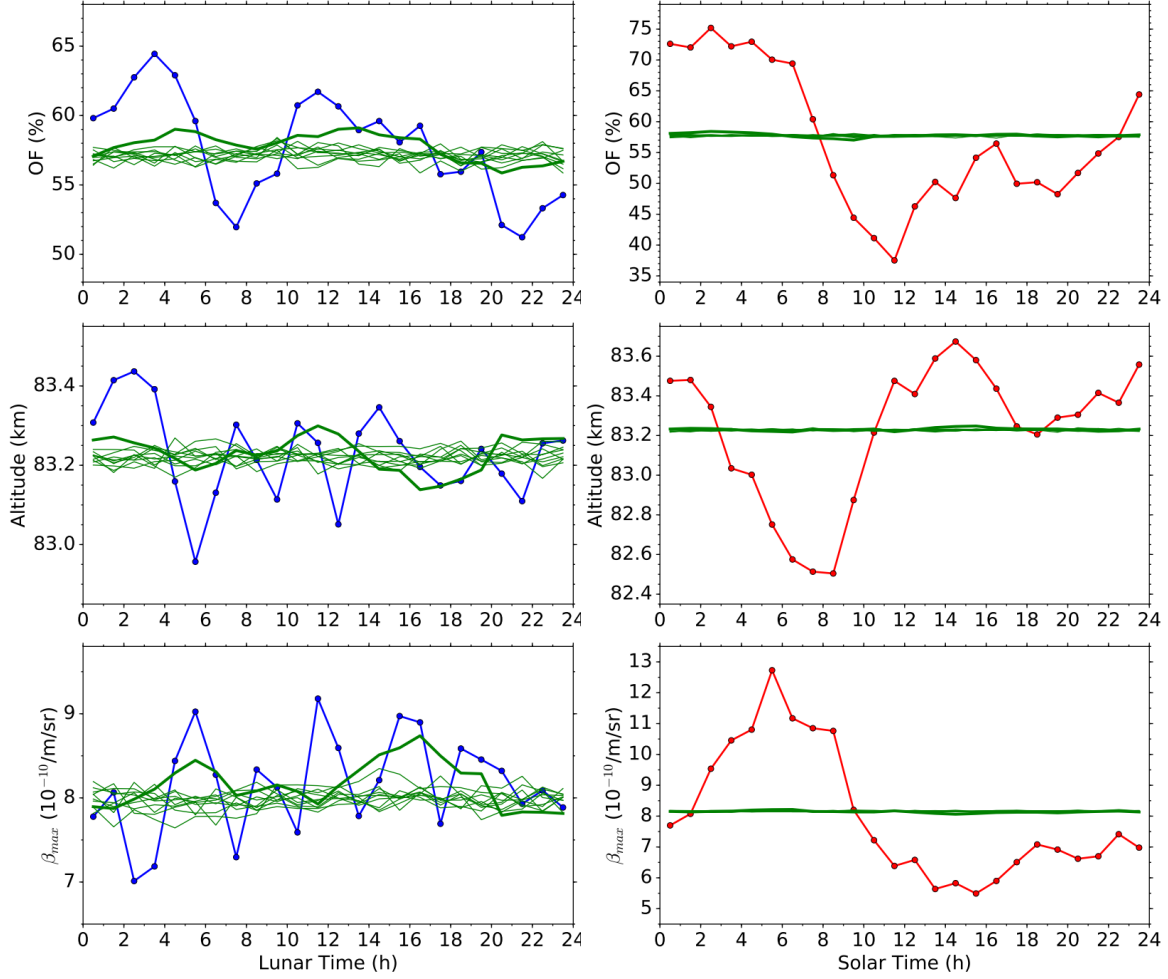
Figure 3. Simulated residual impact of solar onto lunar (left panels) and lunar onto solar (right panels) tidal variations, as introduced by the distribution of measurement times between 19 June and 29 July from 1997 to 2017. Method 1: actual times (thick green curves). Method 2: randomly generated times (thin green curves). Causative variations were reconstructed from harmonic fits with periods of 24, 12, 8 and 6 hours, see Table 1. For details see text. NLC parameters are: occurrence frequency (top), altitude (middle), brightness (bottom). Left panels: measured lunar dependence (blue), simulated impact from solar variations (green). Right panels: measured solar dependence (red), simulated impact from lunar variations (green).

Figure 4. Mean solar amplitudes (top) and phases (bottom) of NLC occurrence frequency (OF, left) and brightness (β_{NLC}, right) between 1 June and 15 August from 1997 to 2017. Diurnal components in red, semidiurnal components in green. Black numbers at the upper panels are correlation coefficients of the harmonic fits for the corresponding altitudes. Colored numbers at the lower panels are vertical wavelengths as calculated from the phase slopes (dashed lines), separated for altitudes below and above 84 km (gray dotted line).
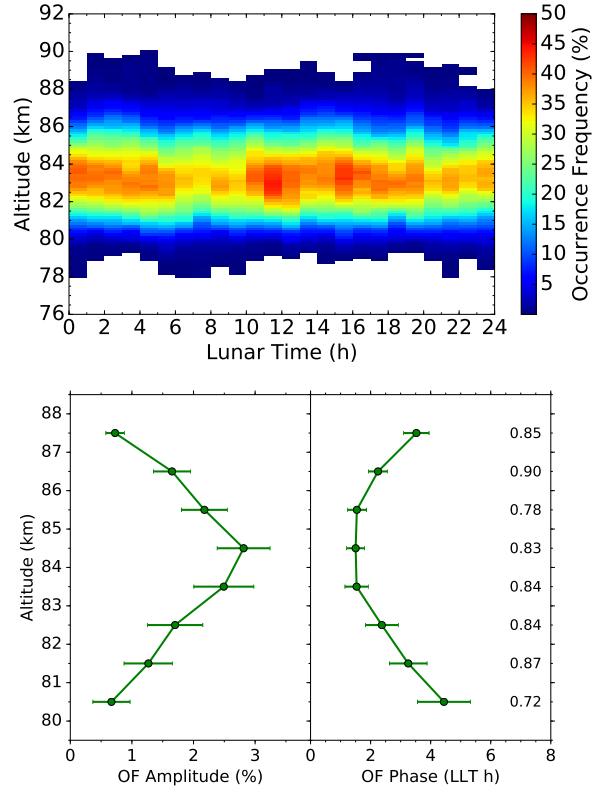
Figure 5. Top: Mean variations of NLC occurrence frequency with altitude and lunar time from 1997 to 2017. The plot contains 3450 hours of lidar measurements between 19 June and 29 July. Bottom: Semidiurnal amplitudes and phases determined from data of the top panel. Black numbers are correlation coefficients of the harmonic fits for the corresponding altitudes.

Table 1. Amplitudes (A) and phases (P) of solar and lunar tidal oscillations as determined from harmonic fits with periods of 24, 12, 8 and 6 hours to the data from 1997 to 2017. Amplitudes are given both in absolute and relative units. Absolute units (abs) are: occurrence frequency (OF) in %, altitude (z_c) in km, maximum brightness ($\beta_{\max}$) in 10^{-10} m^{-1} sr^{-1}, total brightness (β_{tot}) in 10^{-7} sr^{-1}. Relative units (rel) are in % with respect to the mean value. Fit quality is given as correlation coefficient r.

Parameter	Solar				Lunar			
	OF	z_c	$\beta_{\max}$	β_{tot}	OF	z_c	$\beta_{\max}$	β_{tot}
A_{24} (abs)	13.40 ± 1.23	0.33 ± 0.02	2.54 ± 0.14	3.86 ± 0.20	1.68 ± 1.16	0.04 ± 0.02	0.34 ± 0.14	0.79 ± 0.19
A_{12} (abs)	7.32 ± 1.22	0.33 ± 0.02	1.23 ± 0.14	1.56 ± 0.20	3.92 ± 1.27	0.08 ± 0.02	0.16 ± 0.13	0.21 ± 0.17
A_{08} (abs)	2.92 ± 1.25	0.05 ± 0.02	0.22 ± 0.14	0.31 ± 0.19	2.68 ± 1.23	0.06 ± 0.02	0.19 ± 0.14	0.47 ± 0.19
A_{06} (abs)	1.31 ± 1.10	0.03 ± 0.02	0.16 ± 0.12	0.37 ± 0.19	1.04 ± 1.00	0.07 ± 0.02	0.27 ± 0.14	0.47 ± 0.19
A_{24} (rel)	23.46 ± 2.16	0.40 ± 0.03	31.86 ± 1.76	39.09 ± 2.04	2.91 ± 2.01	0.04 ± 0.02	4.21 ± 1.78	7.75 ± 1.85
A_{12} (rel)	12.81 ± 2.14	0.40 ± 0.03	15.38 ± 1.76	15.80 ± 1.93	6.80 ± 2.20	0.10 ± 0.03	1.96 ± 1.63	2.09 ± 1.72
A_{08} (rel)	5.11 ± 2.18	0.06 ± 0.03	2.74 ± 1.75	3.10 ± 1.89	4.64 ± 2.14	0.07 ± 0.03	2.37 ± 1.69	4.63 ± 1.85
A_{06} (rel)	2.30 ± 1.92	0.04 ± 0.03	2.02 ± 1.56	3.76 ± 1.93	1.80 ± 1.73	0.08 ± 0.03	3.27 ± 1.73	4.59 ± 1.85
P_{24}	1.83 ± 0.36	18.13 ± 0.26	4.60 ± 0.21	4.42 ± 0.20	7.37 ± 3.58	0.37 ± 2.73	14.16 ± 1.74	14.48 ± 1.02
P_{12}	3.22 ± 0.32	0.66 ± 0.13	5.73 ± 0.23	5.23 ± 0.24	1.99 ± 0.63	0.94 ± 0.51	5.87 ± 2.46	4.41 ± 2.66
P_{08}	6.70 ± 0.55	3.64 ± 0.65	5.11 ± 0.93	4.24 ± 0.92	2.56 ± 0.62	0.93 ± 0.49	5.05 ± 1.23	5.65 ± 0.58
P_{06}	0.75 ± 2.34	3.92 ± 0.75	1.36 ± 4.08	0.37 ± 2.00	4.28 ± 1.93	1.91 ± 0.31	4.90 ± 0.57	5.13 ± 0.44
r	0.99	0.99	0.98	0.99	0.95	0.79	0.60	0.72